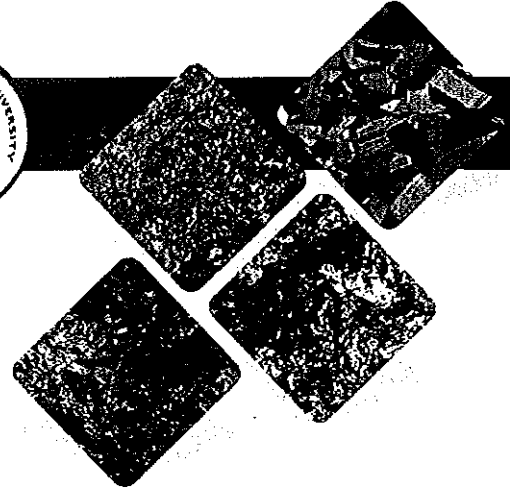


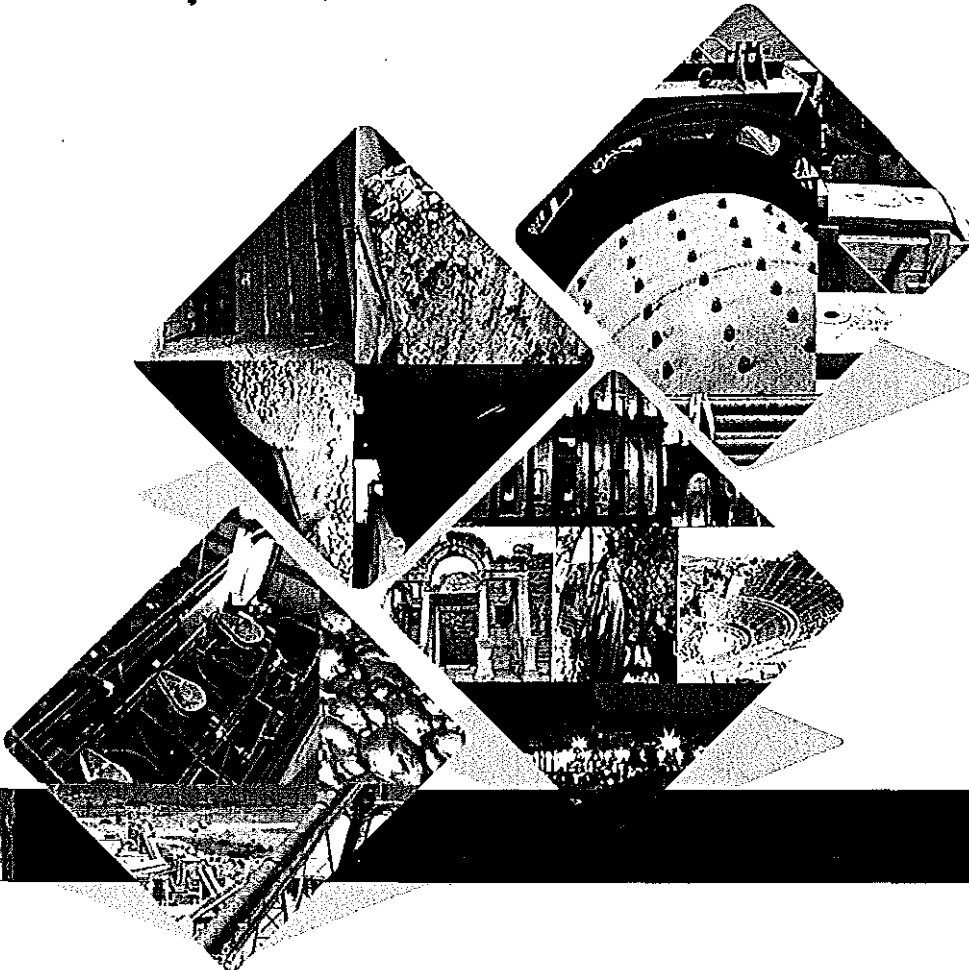


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STATE OF THE ART AND NEW DEVELOPMENTS IN SENSOR BASED SORTING APPLICATIONS

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ABSTRACT: The efficient and sustainable exploitation and processing of primary and secondary raw materials requires new innovative approaches. Sensor-based sorting has undergone a tremendous development during the last decade and has yet become one of the most versatile sorting technologies available for both, the primary and secondary raw materials industry. For most modern recycling plants sensor-based sorting plays a significant role as core separation technology. In the primary raw materials industry, applications have expanded in recent years due to new developments. Starting as a niche application for sorting of diamonds and uranium ores, sensor-based sorting is now used throughout the entire primary raw materials sector for sorting of industrial minerals, metal ores, coal and gems and can bring great benefit to plant operators. This paper briefly introduces into principles of sensor-based sorting, providing an overview of available sensor systems and machine types. Additionally, examples of current research activities and of successful applications in the primary raw materials sector are presented.

1. INTRODUCTION

Sensor-based sorters are known to be used since the 1940s. At that time, differences in the magnetic susceptibility, colour and radioactivity of particles were used as sorting criteria. However, due to low achievable throughputs, sensor-based sorters could only be used for uranium ore sorting and high-value applications such as diamond sorting. [Wotruba, 2006] As a result, sensor-based sorters only played a minor role in the primary raw materials sector until approx. 20 years from now [Wotruba, 2006]. At that time, a new recycling system was introduced in Europe, in combination with a new legal framework. As a result, new approaches for a feasible sorting of waste had to be found, leading to a rapid development and implementation of sensor-based sorters to address these new challenges. Since then, sensor-based sorting has emerged to one of the most important and versatile sorting technologies in the recycling sector. Sensor-based sorters are now used for the

recycling of different materials, such as metals, paper, plastics and glass. In many cases, sensor-based sorters have replaced the conventional handpicking and have proven their reliability under industrial conditions [Neubert et al., 2013].

Developments especially in the computer industry during the last 20 years have increased the potential field of application for sensor-based sorting, especially for the primary raw materials sector. This includes digital picture data processing and an increased processing capacity [Wotruba, 2006]. Development cycles for new generations of sensor-based sorters were comparable to the development in the computer technology, leading to higher throughputs and increased robustness and reliability for each new sorter generation, coming on the market [Arvidson and Wotruba, 2013].

After proving their reliability under industrial conditions, sensor-based sorters

were reintroduced into the primary raw materials sector. Now, sorters with higher throughputs and increased reliability in combination with various sensor systems were available.

In the minerals industry, sensor-based sorters are now found in many different applications such as the sorting of industrial minerals, gem stones, metal ores and aggregates etc. [Neubert et al., 2013]. Hundreds of sensor-based sorters are already used worldwide in many different mineral applications [Wotruba et al., 2010]. Here, sensor-based sorters are used for numerous tasks, such as waste rejection, waste dump retreatment or for the production of final and intermediate products. In the primary raw materials sector, sensor-based sorting is now used to increase processing efficiencies, to treat ore at lower cut-off grades and to reduce the specific overall processing costs. Sensor-based sorting can be applied in areas with arid or arctic climates, due to the fact that no or only low amounts of water are required. Additionally, applications as semi-mobile plants or underground are possible, due to the compact design and small footprint of sensor-based sorters. [Knapp et al., 2014]

2. BASICS OF SENSOR-BASED SORTING

Sensor-based sorting is a term used for all applications where particles are singularly detected by sensors and are ejected by amplified mechanical processes [Wotruba and Harbeck, 2010]. The main difference, compared to conventional sorting technologies, is the fact that the sorting criterion is decoupled from the actual separation force [Wotruba, 2006]. Generally, two types of sensor-based sorters are classified; namely the chute-type sorter and the belt-type sorter. Various sensor-types are available and can be used for simultaneous detection of multiple

material properties. Classification of particles is based on the use of filter- and processing algorithms [Knapp et al. 2014].

The sorting process, used for the separation of particles for both machine types can be subdivided into the following five sub-processes:

- Material conditioning (1)
- Feeding and Presentation (2)
- Detection (3)
- Processing of data (4)
- Mechanical separation (5)

Generally, the first step of sensor-based sorting is the conditioning stage, in which the material is conditioned prior to the actual sorting process. Particles are screened to ensure a suitable size range of particles. Required particle sizes depend on the specific liberation size of valuable minerals. The ratios between the minimum and maximum particles size should not exceed 1:3, to ensure an optimum sorting performance. Throughputs of sensor-based sorters depend on the particle sizes to be sorted, as SBS is a single particle separation technology. Consequently, higher throughputs can be achieved, if larger particles are sorted, whereas throughputs decrease with smaller particle sizes. Feasible throughputs of sensor-based sorters range between a few tons per hour and meter sorting width and can go up to approx. 300 t/h and meter sorting width, depending on the application [Knapp et al. 2014].

The feeding and presentation of particles is a crucial step for the independent detection of particle properties. Overlapping of particles has to be avoided so that material properties can be

detected precisely. Generally, a vibratory feeder is used to transport the material onto a chute (see #1, Figure 1), or onto a conveyor belt (see #1, Figure2). In both cases the material is accelerated, ensuring the isolation of particles. [Neubert et al., 2013].

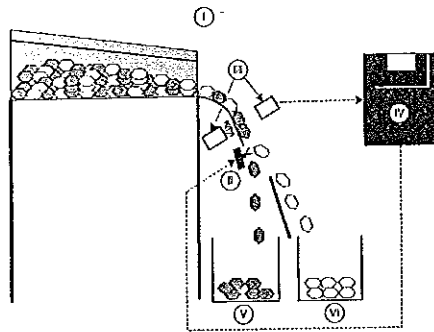


Figure 1: Chute sorter: (I) conditioning, (II) separation unit, (III) emitter- / detector, (IV) data processing, (V) & (VI) product streams [Arvidson and Wotruba, 2013].

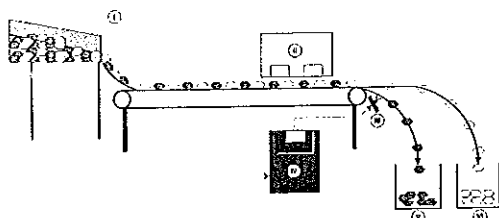


Figure 2: Conveyor belt sorter: (I) conditioning, (II) separation unit, (III) emitter- / detector, (IV) data processing, (V) & (VI) product streams [Arvidson and Wotruba, 2013].

Detection and data processing

Sensors used in sensor-based sorting cover most of the electromagnetic spectrum. Applied measurement principles can be divided into reflective (e.g. optical camera systems) and transmittive measurement principles (e.g. X-ray transmission sensing). Additionally, passive and active sensors are distinguished. Passive sensors detect natural particle properties such as natural radioactivity, whereas active sensors make use of additional radiation sources such as X-rays or light. Combinations of

different sensor types are also available. This enables a more efficient particle separation, but lowers the possible throughput due to higher data volumes to be processed. [Wotruba and Harbeck, 2010] Detected sensor signals are processed by filtering and analysis through appropriate algorithms. This is done to achieve a yes/no decision for each particle so that separation by the separation unit can take place. Processing of particle information by sorting algorithms is limited to approx. 40,000 particles per second and meter sorting width [Wotruba et al., 2014].

Mechanical rejection

Characterized particles are separated from the material stream by mechanical processes. Rejection of particles is done by using of air valves or mechanical flaps. However, air valves are favorable, as a contact free rejection of particles is possible, thus reducing wear. The disadvantage is that compressed, dried air has to be provided for the separation process. The required air pressure, the necessary nozzle pitch and nozzle size are directly correlated to the particle sizes to be sorted.

As specified in the previous chapter, different sensors are available, covering almost the entire electromagnetic spectrum. Based on different functional principles, sensors can be separated as follows:

- I. Sensor for detection of particle surface properties;
- II. Sensors for evaluating of properties from the entire particle;
- III. Sensor for the detection of secondary particle properties such as color, reflection, brightness, conductivity, density, susceptibility and radioactivity;
- IV. Sensors using primary properties such as chemical and mineral

V. composition [Arvidson and Wotruba, 2013].

For each application, the suitable sensor type has to be identified, capable of measuring the required particle information. Gathered information is used for differentiation between valuable and non-valuable particles.

Table 1 summarizes the most frequently applied sensor types used in the minerals industry:

Table 1: Selection of sensor systems used in the primary raw materials sector

Available sensor technologies	Measured characteristics
Optical sensors – CCD color camera	Reflection, absorption, brightness and transmission of visible radiation
X-ray transmission	Transmitted X-ray radiation
Near infrared (NIR)	Reflection and absorption of NIR-radiation
X-ray fluorescence	Reflected X-ray fluorescence under X-ray radiation
Inductive (metal detector)	Electrical conductivity and susceptibility
Radiometric	Natural radioactivity

Fields of application for sensor-based sorting in the primary raw materials sector

Sensor-based sorting is used in a broad range of applications in both, the primary raw materials sector, but also for recycling. In the mining sector, the probably most common application for SBS is waste rejection, where barren rock is separated at an early stage of the processing chain and even underground. The schematic principle is shown in Figure 3. By doing so, particles with no or low valuable content are separated at an early stage, thus reducing downstream operational costs. With this technique, costs for energy, wear, reagents and required processing water is reduced. The

run of mine ore is usually crushed and screened, before being fed to the sorter. The material stream is separated and only valuable, worthwhile particles are further treated in additional processing steps, together with undersized particles from the previous screening stage.

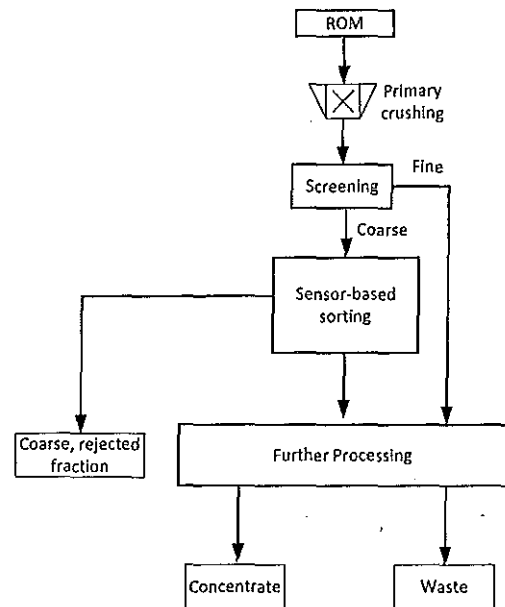


Figure 3: Schematic principle of sensor-based sorting used for waste rejection

At the same time, coarse waste particles are deposited or remain underground for backfilling, thus reducing transportation costs. Moreover, operational costs for the beneficiation plant, especially milling costs, as well as necessary capital expenditures can be reduced, while higher contents of pre-concentrates increase efficiencies of processing operations [Salter and Wyatt, 1991].

Besides that, sensor-based sorting can also be used for ore-type separation. Here, different ore types can be treated by distinct conventional processing methods to obtain optimal recovery, once having being separated by sensor-based sorting. An additional application is in the production of intermediate or final products. Examples are the use of X-ray transmission-, X-ray fluorescence as well

as optical color sorting for diamonds, calcite, talc as well as rock salt [Wotruba, 2006].

Sensor-based sorting is also used for the reclamation of old abandoned waste dumps, which can still contain significant amounts of valuables. Reclaimed, valuable particles can be blended into an existing processing plant, thus reducing the necessary mining rate. Figure 4 illustrates the basic principle of waste dump reclamation using sensor-based sorting:

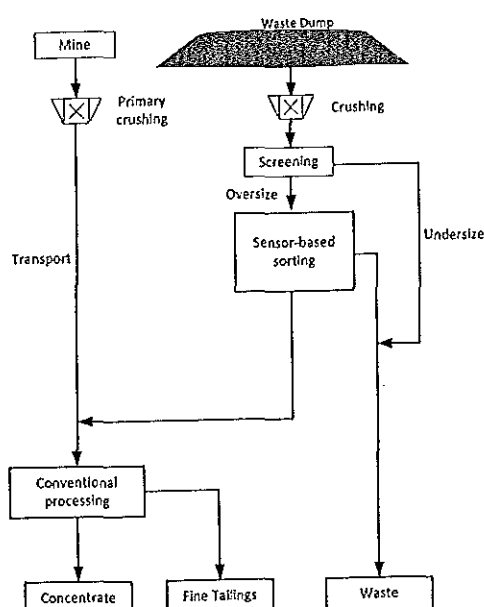


Figure 4: Schematic principle of sensor-based sorting used for waste rejection [Knapp et al., 2014]

New developments and research fields in sensor-based sorting of minerals

The full potential of sensor-based sorting is, without any doubt, far from being fully exploited. Initial developments were mainly focused on sensor development and performance. Later, it showed that difficulties mainly occurred as mechanical problems such as dust, wear or blinding of lamps, etc. As a result, current developments integrate all sub-processes to improve overall performance.

Consequently, research projects focus on various aspects of sensor-based sorting. Important subjects include the development of improved image processing algorithms such shape- and pattern recognition and the development of new sensors such as monochromatic lasers, as used in the food industry. Increasing the possible throughput of sensor-based sorters is a constant requirement, mainly driven by mass resources such as iron and copper ore. This challenge is addressed by optimizing the material presentation (currently, a maximum of 6 m/s is possible), by an increased sorting width per machine (up to 3m) and by the use of faster hard- and software.

In some cases, secondary properties such as colour, transparency, conductivity or brightness cannot be used for sorting of particles. The reason is that some minerals can, e.g. be found in many different colours like calcite or fluorite. In this case, the detection of the secondary property "colour" would not be sufficient. With the development of new sensors, the detection of "primary" properties was facilitated, meaning that characteristics, specific for a certain mineral or grade can be detected by suitable detectors. Since a few years (and also pushed by developments in the recycling industry), sensors exist, which are able to detect "primary" properties like absorption of distinct wavelengths (e.g. NIR sensors), or the elemental composition (XRF sensors) of particles. In the near-infrared (NIR)-spectrum, NIR sensors can be used for mineral identification [Arvidson and Wotruba, 2013]. Enormous potential for sorting applications lies in the use of XRF sensors. Even though, in this case, only surface properties are used for particle characterization, the use of this technology comes close to the minerals processors dream, since the sorting upon chemical composition and grade is

possible. Compared to its use for laboratory analysis and even process control, the measuring time is extremely short despite low spatial resolution of currently several centimeters, leading to a low signal-to-noise ratio. Nevertheless, the measurement of heavy elements down to a detection limit of 0,1 % is possible, not based on the absolute, but relative counting rate of the detector.

For metal ores and coal, X-ray transmission sorting has shown very good results in the actual industrial plants, like in the Mittersill scheelite mine (Austria). This technology is well known from the airport luggage scanners and can identify elements according to their atomic density. Especially heavy elements like tungsten absorb γ -rays nearly complete, and tungsten minerals like scheelite or wolframite can be recognized as black or grey dots within a rock and can be identified by their contrast to the matrix. The separation of light coal and heavy stone works nearly perfect (and completely dry). First trials with diamonds have shown good results. The potential for sulphides and metal oxide ores (cassiterite, tantalite, etc.), but also for industrial minerals like barite or fluorite has been successfully evaluated in laboratory tests, and the first XRT industrial plant for fluorite sorting has been installed in Germany underground.

As explained, available detection time of sensors for SBS is limited. In some cases, particle with low grade values (ppm-range) are difficult to separate by the detection of primary properties such as the elemental composition. As a result, indicators with a sufficient correlation to the valuable content are used. Here, specific minerals and/or elements are used to facilitate the distinction between valuable and non-valuable particles [Neubert et al., 2013] [Arvidson and Wotruba, 2013] One example is the use

of alteration minerals, as indicator for the presence of valuable particles.

At present, not more than two sensors are used in an effort to reduce the duration required for data processing. In principle, each combination of sensors is possible which gives -theoretically- additional information for particle characterization. Yet, combinations of optical and NIR, optical and inductive or XRT in combination with inductive sensors are used. [Arvidson and Wotruba, 2013]

3. SUMMARY

For various applications in both, the minerals and recycling industry, sensor-based sorting has become an important technology for an efficient and sustainable processing of raw materials. However, even though the technical diversity and applicability of this technology is evident, the use of sensor-based in the minerals industry is not as common as the usage compared to the recycling of raw materials. With an ongoing research and technical development of all sub-processes, it becomes clear that applications for sensor-based sorting in the minerals sector will expand, unleashing its full potential.

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